The lateral retroperitoneal transpsoas approach is increasing in popularity among spine surgeons. However, this surgical corridor is close to and involves navigation around retroperitoneal structures (peritoneal sac, great vessels, kidneys, and lumbar plexus). Recent studies have revealed that the most frequent complication of the lateral retroperitoneal transpsoas approach relates to injury of the lumbar plexus. Although real-time nerve monitoring has decreased the incidence of lumbar plexus injury, it remains the most common complication.

Direct and/or indirect injury to nerves of the lumbar plexus can produce either transient or permanent sensory and/or motor deficits. Assessing the degree of nerve injury is important not only for localization and prognosis but also in determining the timing of surgical intervention versus continued observation. An understanding of the classification of nerve injuries provides the physiological

Analysis of lumbar plexopathies and nerve injury after lateral retroperitoneal transpsoas approach: diagnostic standardization

A review

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Object. The minimally invasive lateral transpsoas approach has become an increasingly popular means of fusion. The most frequent complication is related to lumbar plexus nerve injuries; these can be diagnosed based on distribution of neurological deficit following the motor and/or sensory nerve injury. However, the literature has failed to provide a clinically relevant description of these complications. With accurate clinical diagnosis, spine practitioners can provide more precise prognostic and management recommendations to include observation, nerve blocks, neurodestructive procedures, medications, or surgical repair strategies. The purpose of this study was to standardize the clinical findings of lumbar plexopathies and nerve injuries associated with minimally invasive lateral retroperitoneal transpsoas lumbar fusion.

Methods. A thorough literature search of the MEDLINE database up to June 2012 was performed to identify studies that reported lumbar plexus and nerve injuries after the minimally invasive lateral retroperitoneal transpsoas approach. Included studies were assessed for described neurological deficits postoperatively. Studies that did attempt to describe nerve-related complications clinically were excluded. A clinically relevant assessment of lumbar plexus nerve injury was derived to standardize early diagnosis and outline prognostic implications.

Results. A total of 18 studies were selected with a total of 2310 patients; 304 patients were reported to have possible plexus-related complications. The incidence of documented nerve and/or root injury and abdominal paresis ranged from 0% to 3.4% and 4.2%, respectively. Motor weakness ranged from 0.7% to 33.6%. Sensory complications ranged from 0% to 75%. A lack of consistency in the descriptions of the lumbar plexopathies and/or nerve injuries as well as a lack of diagnostic paradigms was noted across studies reviewed. Sensory dermal zones were established and a standardized approach was proposed.

Conclusions. There is underreporting of postoperative lumbar plexus nerve injury and a lack of standardization of clinical findings of neural complications related to the minimally invasive lateral retroperitoneal transpsoas approach. The authors provide a diagnostic paradigm that allows for an efficient and accurate classification of postoperative lumbar plexopathies and nerve injuries.

Key Words • lumbar plexus • femoral nerve injury • complication • lateral retroperitoneal transpsoas approach • lumbar spine surgery • functional neurosurgery
basis for prognosis and management. The predominant classification schemes proposed to describe nerve damage are those of Seddon\textsuperscript{53} and Sunderland.\textsuperscript{56} The diagnosis of lumbar plexus injury can be made based on distribution of motor and sensory findings postoperatively, with subsequent supportive electrophysiological studies. The current literature lacks standardization when describing the different clinical scenarios of nerve injury after minimally invasive lateral interbody fusion. Without standardization, we are unable to identify the most frequent type of nerve/plexus complication or provide early prognostic and management recommendations, including continued observation, nerve blocks, neurodestructive procedures, medications, or surgical repair strategies. In this study we performed a systematic review and meta-analysis in an attempt to summarize and combine the published data on lumbar plexus nerve injuries related to the minimally invasive lateral retroperitoneal transpsoas approach. In doing so we also illustrate the most common clinically relevant lumbar plexus nerve injuries and provide a management algorithm.

Methods

A systematic MEDLINE database literature search was performed to determine how investigators described lumbar plexus nerve injuries after minimally invasive lateral retroperitoneal transpsoas surgery. The search was limited to clinical studies in the English literature up to June 2012 with the following key words: “XLIF,” “DLIF,” “lateral interbody fusion,” “retroperitoneal,” or “transpsoas.” Inclusion criteria were studies that clinically described complications related to surgical approach. Anatomical descriptions and studies without relevant complications and those without adequate clinical descriptions were excluded from the cohort. A total of 18 studies were selected with a total of 2310 patients. Clinical descriptors were extracted, characterized, and cross-referenced with specific nerve functions of the lumbar plexus. Subgroup analysis of related transient hip flexor weakness was performed. Clinically relevant lumbar plexopathies were illustrated with a standardized diagnostic paradigm to allow for rapid and more accurate clinical evaluation. A management algorithm was subsequently proposed.

Results

A total of 304 patients (13.2%) with possible plexus-related complications were described. Transient hip flexor weakness was attributed to splitting of the psoas muscle. Subgroup analysis without transient hip flexor weakness resulted in 198 patients (8.6%). Persistent hip flexor weakness of more than 6 months’ duration was grouped with plexus-related complications. Incidence of documented nerve root injury and postoperative abdominal paresis ranged from 0% to 3.4% and 4.2%, respectively.\textsuperscript{6,318} The complication profile across all studies included thigh numbness, groin paresthesia/pain, psoas weakness, quadriceps weakness, abdominal paresis, and root injury. There was no report of autonomic dysfunction. The complication rates and descriptions reported varied greatly in the literature; motor weakness ranged from 0.7% to 33.6%,\textsuperscript{12,25,30,34,42} Sensory complications ranged from 0% to 75%.\textsuperscript{3,6,7,23,26,29} Descriptive analysis of these findings was limited in all of the studies reviewed. Authors used generalized terms such as “thigh numbness,” “foot numbness,” “motor radiculopathy,” “leg weakness,” and so on. Also, when weakness was reported, authors tended to neglect or not report sensory findings.\textsuperscript{6} The most common reported finding was hip flexor weakness and “thigh numbness” (Table 1). Once the lack of standardization of clinical description was determined, we established a standardized approach with SDZs.

A Standardized Approach With Clinical SDZs

The intended trajectory of the lateral retroperitoneal dissection is midvertebral body in the anteroposterior plane for placement of an intervertebral cage. The approach is anterior to the neural foramen and hence vulnerable to lumbar nerve injury rather than specific root injury. Lumbar nerves have contributors from multiple roots, and therefore a much more clinically significant outcome if injured. All nerves of the lumbar plexus have a dermal sensory representation, except for the intrinsic motor branches supplying the psoas muscle. Clinical diagnosis of specific lumbar plexus nerve injuries can sometimes depend on overlapping sensory deficits, which can make diagnostic evaluation more difficult (Table 2 and Fig. 1).

Iliohypogastric, Ilioinguinal, Genitofemoral, and Subcostal Nerves (SDZ I)

The iliohypogastric, ilioinguinal, genitofemoral, and subcostal nerves have overlapping sensory fields (dermatome) and motor innervations. Injury to one or a combination of these nerves during the retroperitoneal approach can result in pain and/or sensory deficit or paresis, and has been well established in the literature.\textsuperscript{9,10,21,22} Clinical diagnosis to discern specific nerves can be challenging.\textsuperscript{25} Spine practitioners should clinically identify injury to these nerves, which can tailor their follow-up and prognostic recommendations. The ilioinguinal and genitofemoral nerves are involved in the sensory and motor limbs of the cremasteric reflex in males, and hence this reflex may be absent with injury of these nerves. Involvement of the iliohypogastric, ilioinguinal, genitofemoral, and subcostal nerves can be clinically suspected when paresthesia, pain, or numbness is present in SDZ I (Fig. 1). This zone is defined to be along the ilioinguinal line, extending approximately 10 cm below the ASIS. The iliohypogastric nerve also has a lateral branch that innervates skin over the greater trochanter. If an SDZ I deficit is detected, follow-up should be tailored to evaluate for possible abdominal paresis. Abdominal paresis may not be detected in the early postoperative setting but may be present in the follow-up period.\textsuperscript{9} (Fig. 2).

Lateral Femoral Cutaneous Nerve (SDZ II)

The LFCN, a purely sensory nerve, courses outside of the psoas muscle and can be injured with aggressive dissection of the retroperitoneal adipose tissue. Its clini-
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<table>
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<tr>
<th>Authors &amp; Year</th>
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<td>3</td>
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<td>4</td>
<td>ant tibialis (1 pt &gt;6 mos)</td>
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<td></td>
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<td>1</td>
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<td></td>
<td></td>
<td>1</td>
<td>quadriceps weakness</td>
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* ant = anterior; pts = patients.
† Some involving multiple myotomes.

cal syndrome, termed meralgia paresthetica, describes sensory dysesthesia of the anterolateral thigh. The LFCN relays sensory impulses from SDZ II (Fig. 1) and pierces the fascia lata approximately 3 cm below the ASIS. Zone II is defined to be lateral to the line from the ASIS to the lateral aspect of the patella (Fig. 2).

**Femoral Nerve (SDZ III)**

The clinical findings of a femoral nerve injury involve a specific pattern of both motor and sensory deficits. This nerve has the largest myotomal and dermatomal representation in the proximal lower extremity and is responsible for the patellar deep tendon reflex. It has branches to the sartorius, pectineus, rectus femoris, iliacus, psoas, and vastus muscle groups. The medial femoral cutaneous, intermediate femoral cutaneous, infrapatellar, and saphenous sensory branches comprise SDZ III (Fig. 1). This is defined as the region medial to the ASIS-patellar line.
and extends distally to the medial malleolus. When Zone III deficits are suspected, practitioners should highly suspect motor involvement as well. A thorough motor examination is warranted to document knee extension strength and the presence of a patellar reflex.

**Obturator Nerve (SDZ IV)**

The sensory component of the obturator nerve corresponds to SDZ IV (Fig. 1), whereas its motor innervations involve muscles of adduction. SDZ IV is defined as the cutaneous patch of the inner thigh just distal to the midpoint of the thigh. The size of the sensory component may vary and can overlap with the sensory field of the femoral nerve. When an SDZ IV deficit is suspected, especially in the absence of an SDZ III deficit, leg adduction should be evaluated for suspicion of obturator nerve injury.

**Modifying Factors**

Although sensory dermal zones represent a major component of the physical examination, the presence or lack of a motor deficit should also be reported accordingly. Certain lumbar plexus nerves carry only sensory inputs (LFCN and genitofemoral nerve in women). The intrinsic psoas muscle nerve branches are the only pure motor lumbar plexus nerves. A patient may, however, have only the sensory manifestation of injury to a nerve supplying both motor and sensory innervation. It is less likely for the motor deficit to exist without a sensory abnormality because afferent sensory nerves are of relatively small caliber and are more vulnerable than the myelinated larger-caliber motor component. Direct postoperative radicular pain is also unlikely because radicular pain is related to dorsal root ganglion compression or injury rather than injury to the nerve axons. Diffuse retraction injury to the main components of the plexus can occur, with resultant deficits in multiple zones (plexus injury neurapraxia; see Fig. 2).

### Discussion

#### Mechanism of Nerve Injury

Approach-related complications of the retroperitoneal transpsoas approach that occur despite intraoperative nerve monitoring have been well documented. Iatrogenic nerve injury can be secondary to direct mechanical compression, laceration, stretch/traction, or indirect ischemia. The anatomical properties of peripheral nerves (lumbar plexus) are closely related to their susceptibility to injury. Sharp or lacerating nerve injury involves disruption of both the axonal and stromal component of a nerve. The degree of functional loss of these injured nerves depends on whether the lacerating injury is partial (Sunderland Grade II–IV) or complete (neurotmesis; Sunderland Grade V). Regeneration of transected nerves may be poor because of neuroma and scar formation; hence surgical repair is required for the possibility of functional recovery.5

Mild compression and stretch/traction are associated with ischemia of the involved nerve.5,36 A high degree of nerve compression, excessive stretch, or stretch over a prolonged period of time can lead to structural deformation and functional failure.19,24 Mechanical susceptibility or, conversely, a nerve’s tensile strength is provided by the epineurium and perineurium with their abundance of collagen and elastin.35,37 The degree of resulting structural integrity and ischemia is related to the prognosis of functional recovery and can be the difference between recoverable neurapraxia (Sunderland Grade I) and more severe
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axonotomy (Sunderland Grade III–IV). Injury to lumbar plexus nerves during the transpsoas approach is multifactorial and may involve stretch, regional compression, and segmental ischemia.

Even though EMG monitoring is critical during the early stages of the approach and during the retractor placement, false-positive or false-negative readings can provide misleading information regarding the location of the main motor components of the lumbar plexus. Furthermore, nerve injury can occur from prolonged retraction even with “normal” intraoperative EMG readings. There is a large degree of variability between studies regarding incidence of both motor and sensory complications. Authors’ general descriptions of lumbar plexus–related complications makes clinical diagnosis difficult (Table 1). “Thigh numbness” is not well enough defined across the studies reviewed to differentiate appropriately the anterior cutaneous branches of the femoral nerve from the LFCN. Knight et al. specifically reported an LFCN injury in 6 of 9 patients with approach-related complications. They also reported L-4 root injury in 2 patients; however, they did not delineate how they confirmed the diagnosis, postulated the mechanism of injury, or described the pattern of injury. On the other hand, Cahill et al. reported femoral nerve injury only when the muscular motor branches were affected, omitting the sensory component of the nerve, with the resultant lower incidence of femoral nerve injury in their series. The corridor to the disc space is more vulnerable to nerve injury than is the specific nerve root. Isaacs et al. described complications related to specific muscle group involvement but did not specify associated dermatomal findings. It is important to realize that femoral nerve injury is not only motor but also sensory. In our experience, postoperative motor deficits were usually associated with nerve-specific sensory deficits. Defining SDZs to correlate with myotomal findings allows for standardization of clinically relevant lumbar plexopathies.

Defining SDZs

Defining clinically relevant sensory zones in combination with motor findings allows for descriptive uniformity and rapid clinical assessment. Therefore, clearly defining nerves of the lumbar plexus that are affected and that possibly indicate at what stage of the approach the particular nerve may have been injured allows the spine practitioner to tailor his or her approach. A Zone I or Zone II deficit with or without motor findings (abdominal wall paresis) would suggest injury and/or irritation of the nerves outside of the psoas muscle, suggesting that more care should be taken during access and dissection of the retroperitoneal space. The presence of weakness should provoke investigation for associated sensory deficits, particularly in Zones III and IV. Sensory distribution of the femoral nerve (SDZ III) includes the saphenous nerve distally, which can be confused with L-4 nerve root injury when the deficit is that of the femoral nerve (Fig. 1).

Hip Flexor Weakness and Pain

Transient hip flexor weakness is the most common complication reported in the literature after a transpsoas approach. Investigators have attributed it to the muscle splitting that is required by the approach. These patients have no sensory deficit, but have transient iliopsoas muscle weakness (< 3 months) and associated pain with at-

Fig. 1. Illustration showing SDZs for clinical examination: SDZ I—iliohypogastric, ilioinguinal, genitofemoral, and subcostal nerves; SDZ II—LFCN; SDZ III—femoral nerve; and SDZ IV—obturator nerve.
tempted hip flexion. Full recovery should be expected. However, nontransient weakness can occur and is usually associated with other lumbar plexus nerve injuries. The ilioptosas muscle has multiple intrinsic short motor roots that supply it. Painless hip flexor weakness that is very slow to recover may be due to a purely motor branch injury. The isolated psoas muscle is best examined with the patient in the sitting position and asked to flex the hip more than 90°. The iliacus muscle is involved in hip flexion less than 90°. Even with injury to the intrinsic motor fiber of the psoas, the prognosis for recovery can be considered good. This is because there are multiple relatively short nerves that innervate the psoas. Given the short distance, timing for axonal regeneration is more favorable compared with longer motor nerves that innervate other lower myotomes (that is, the femoral nerve).

Femoral Nerve Injury

A complete lesion of the femoral nerve within the psoas muscle will result in loss of patellar reflex, paralysis of knee extension, weakness of hip flexion, and sensory deficit in SDZ III. With a high degree of axonotmesis or Grade V neurotmesis (complete injury) significant muscle atrophy is expected. Complete neurapraxia (first degree), however, will have significant improvement in the first 3 months, although initially it may resemble high-degree axonal injury. A partial injury (partial/mild neurapraxia) can result in quadriceps paresis that may be clinically relevant when the patient initially ambulates postoperatively. In mild neurapraxia, with initial motor strength better than antigravity (motor scale > 3/5), rapid and full recovery is expected. Even initially complete neurapraxia usually has a good outcome compared with axonotmesis or neurotmesis, which may require surgical intervention.

Approach to Clinical Examination and Management

The approach to the postoperative examination should be systematic and methodical. The presence of weakness should prompt investigation for associated sensory findings to better ascertain the nerves involved (Fig. 3). If no weakness can be identified, focusing on sensory findings can indicate partial nerve injury or injury to purely sensory nerves. Sensory examination should differentiate anesthesia from pain and/or paresthesia (nerve dysfunction). Diagnosis of neuropathic pain can be challenging; there may be spontaneous or a stimulus-evoked sensation of burning or shooting pain. Stimulus-evoked pain is divided into allodynia (dynamic, static, thermal), which is evoked by nonpainful stimulus; or hyperalgesia, which is a disproportionate response to painful stimulus (pinprick). Moreover, spontaneous neuropathic sensory dysfunction is commonly described as itching, tingling, “pins and needles,” or wetness. A thorough physical examination and description of sensory findings can help differentiate neuropathic dysfunction from myofascial type pain.

Electrodiagnostic Evaluation

Electrodiagnostic studies are helpful in assessing injury to myelin and axons; however, the electrodiagnostic examination cannot evaluate neuronal stroma. Some authors describe a 6th-degree injury to emphasize that most lesions are mixed neurapraxia and axonotmesis of varying degrees. Neurapraxia resolves with remyelination in approximately 3 months. A suggested interval for performing electrodiagnostic studies for closed injuries without clinical recovery is 6 weeks and then 3 months. If there is evidence of clinical recovery, no further electrodiagnostic testing is recommended. If there is no further clinical recovery, a limited EMG needle examination is repeated at 1-month intervals at 4, 5, and 6 months postinjury to assess for early reinnervation. Localization by electrodiagnostic study is dependent on demonstrating conduction block on nerve conduction studies and on assessing EMG abnormalities in a root, plexus, or periph-
eral nerve distribution. Timing for obtaining postoperative EMG studies may vary by surgeon preference. Given the transient nature of some lumbar plexus injuries, the majority of patients recover within the first 3–6 months, suggesting a predominantly neurapraxic lesion, although studies quantifying the time to resolution are lacking.4,14,16 In our experience we allow 6 weeks of observation prior to obtaining postoperative EMG studies in a patient with a neurological deficit to confirm our clinical suspicions and identify the distribution of injury, followed by a study at 3 months. With no further clinical recovery, a limited EMG needle examination is performed at 1-month intervals at 4, 5, and 6 months postinjury to evaluate for early reinnervation. At each interval, if there is clinical improvement no further electrodiagnostic examination is recommended.

No direct correlation exists between the Medical Research Council muscle motor grade and type of nerve injury. Intuitively, if the patient has any motor movement postinjury, one can assume that some motor fibers remain intact. Conversely, if the patient is plegic, he or she can have either complete neurapraxia, axonotmesis, or neurotmesis; hence no conclusion can be made about the integrity of the motor nerves. An EMG needle examination at 6 weeks is helpful to confirm whether there is partial axonal loss by demonstrating fibrillations and positive waves. The study may also be useful in localizing and discerning the type and degree of injury.

The severity of postoperative weakness can also suggest good or poor prognosis for recovery. In our experience, if the immediate postoperative motor deficit is a decline of 2 or less on the motor scale (≥3/5 motor scale score; that is, antigravity), then the potential for recovery is good. However, if the patient's deficit is not antigravity (≤2/5 motor scale score), the degree of motor nerve injury is higher and hence the potential for meaningful recovery is less, unless the complication is isolated hip flexor weakness. High-degree isolated hip flexor weakness can have good potential for recovery, especially if associated with pain.

Limitations of the Study

We recognize the limitations of defining clinical zones. The diagnosis of specific lumbar plexopathies and specific nerve injuries is based on interpretation of anatomical, clinical, and electrophysiological data. Interpretation of clinical findings introduces a subjective component to the initial diagnosis, especially because there can be overlap of defined zones or if multiple SDZs are involved. Further large-scale and independent validation studies are needed to validate the proposed SDZ classification.

Conclusions

To decrease the morbidity related to the minimally
invasive lateral retroperitoneal transpsoas approach and to formulate algorithms of management, it is necessary to identify nerve injury patterns correctly. The lack of standardization of postoperative lumbar plexopathies and nerve injuries limits accurate and timely diagnosis, which may be useful in prognostication and management. The diagnosis relies on careful evaluation of the clinical findings, which can be particularly difficult to assess because there is considerable overlap of sensory dermatomes. By standardizing the approach to lumbar plexus evaluation, spine practitioners can rapidly and accurately localize affected nerves and the level of injury to guide their postoperative management.

**Disclosure**

Dr. Uribe is a consultant for NuVasive. The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Uribe, Ahmadian. Acquisition of data: Ahmadian. Analysis and interpretation of data: Uribe, Ahmadian, Abel. Drafting the article: Ahmadian, Abel. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Uribe. Administrative/technical/material support: Uribe, Ahmadian, Deukmedjian. Study supervision: Uribe.

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